Motor Control Exercise for Persistent, Nonspecific Low Back Pain: A Systematic Review

Luciana G Macedo, Christopher G Maher, Jane Latimer, James H McAuley

Background. Previous systematic reviews have concluded that the effectiveness of motor control exercise for persistent low back pain has not been clearly established.

Objective. The objective of this study was to systematically review randomized controlled trials evaluating the effectiveness of motor control exercises for persistent low back pain.

Methods. Electronic databases were searched to June 2008. Pain, disability, and quality-of-life outcomes were extracted and converted to a common 0 to 100 scale. Where possible, trials were pooled using Revman 4.2.

Results. Fourteen trials were included. Seven trials compared motor control exercise with minimal intervention or evaluated it as a supplement to another treatment. Four trials compared motor control exercise with manual therapy. Five trials compared motor control exercise with another form of exercise. One trial compared motor control exercise with lumbar fusion surgery. The pooling revealed that motor control exercise was better than minimal intervention in reducing pain at short-term follow-up (weighted mean difference=−14.3 points, 95% confidence interval [CI]=−20.4 to −8.1), at intermediate follow-up (weighted mean difference=−13.6 points, 95% CI=−22.4 to −4.1), and at long-term follow-up (weighted mean difference=−14.4 points, 95% CI=−23.1 to −5.7) and in reducing disability at long-term follow-up (weighted mean difference=−10.8 points, 95% CI=−18.7 to −2.8). Motor control exercise was better than manual therapy for pain (weighted mean difference=−5.7 points, 95% CI=−10.7 to −0.8), disability (weighted mean difference=−4.0 points, 95% CI=−7.6 to −0.4), and quality-of-life outcomes (weighted mean difference=−6.0 points, 95% CI=−11.2 to −0.8) at intermediate follow-up and better than other forms of exercise in reducing disability at short-term follow-up (weighted mean difference=−5.1 points, 95% CI=−8.7 to −1.4).

Conclusions. Motor control exercise is superior to minimal intervention and confers benefit when added to another therapy for pain at all time points and for disability at long-term follow-up. Motor control exercise is not more effective than manual therapy or other forms of exercise.

LG Macedo, PT, MSc, is a PhD student at The George Institute for International Health, The University of Sydney, PO Box M201, Missenden Rd, Camperdown, Sydney, New South Wales, 2050 Australia. Address all correspondence to Ms Macedo at: lmacedo@george.org.au.

CG Maher, PT, PhD, is Director, Musculoskeletal Division, The George Institute for International Health, The University of Sydney.

J Latimer, PT, PhD, is Associate Professor, The George Institute for International Health, The University of Sydney.

JH McAuley, PhD, is Research Manager, The George Institute for International Health.

[Macedo LG, Maher CG, Latimer J, McAuley JH. Motor control exercise for persistent, nonspecific low back pain: a systematic review. *Phys Ther.* 2009;89:9–25.]

Low back pain (LBP) is one of the main causes of disability, and, despite its high prevalence, the source of pain is not established in the majority of cases and the term "nonspecific low back pain" is used.[1–4] One factor that has been proposed as important in the genesis and persistence of nonspecific LBP is stability and control of the spine.[4] Studies of individuals with LBP have identified impairments in the control of the deep trunk muscles (eg, transversus abdominis and multifidus) responsible for maintaining the stability of the spine.[5–8] For example, activity of the transversus abdominis muscles[9] and the multifidus muscles[7] is delayed during arm movements (that challenge the stability of the spine) in individuals with LBP. Furthermore, there is evidence of decreased cross-sectional area[10] and increased fatiguability[11] and a suggestion of increased intramuscular fat in the paraspinal muscles of individuals with LBP.[12] Therefore, theoretically, an intervention that aims to correct the changes occurring in the deep trunk muscles and that targets the restoration of control and coordination of these muscles should be effective in the management of persistent LBP.

Motor control exercise was developed based on the principle that individuals with LBP have a lack of control of the trunk muscles. The idea is to use a motor learning approach to retrain the optimal control and coordination of the spine. The intervention involves the training of preactivation of the deep trunk muscles, with progression toward more complex static, dynamic, and functional tasks integrating the activation of deep and global trunk muscles.[13,14]

Although a number of laboratory studies supporting the underlying mechanism of action of motor control exercises have been published in the last decades,[5,9,15] the clinical effectiveness of motor control exercise for persistent LBP is still unclear.[5,9,15] Three systematic reviews of motor control exercise have been published[16–18]; however, the authors of these reviews searched the literature only up until October 2005. Hauggaard and Persson,[17] the authors of the latest published review, included 10 trials testing the efficacy of motor control for acute, subacute, and chronic LBP. The review used a simple descriptive approach to summarize the results of each individual trial. Rackwitz et al[18] summarized the results of 7 randomized controlled trials of acute, subacute, and chronic LBP, and although they used a better approach to summarize the available evidence, no meta-analytical analysis with pooling of the data was used. Ferreira et al[16] summarized the results of 13 randomized controlled trials of recurrent, acute, subacute, and chronic LBP and cervical pain. This review was the only one that included a meta-analytical approach; however, only a few trials were pooled, limiting the generalization of the results. A meta-analytical approach is superior to the other forms of analysis for systematic reviews because it provides a treatment effect size with 95% confidence interval (CI).

Consistent with the Cochrane Collaboration,[19] we felt that an updated review incorporating new randomized controlled trials would make a useful contribution to the literature. In addition, a meta-analytical approach, which has not been widely used in the previous published systematic reviews, can potentially add useful information about the magnitude of the effect of motor control exercises. Because our main interest was to study persistent LBP and guidelines suggest that persistent and acute LBP should be considered separately,[19–21] we included only trials studying patients with LBP that persisted beyond the acute phase. The term "persistent low back pain" is used to describe subacute, chronic, and recurrent pain. Thus, the objective of this study was to systematically review randomized controlled trials testing the effect of motor control exercise in patients with persistent, nonspecific LBP.

Method

Data Sources and Searches

A computerized electronic search was performed to identify relevant articles. The search was conducted on MEDLINE (1950 to June 2008), CINAHL (1982 to June 2008), AMED (1985 to June 2008), PEDro (to June 2008), and EMBASE (1988 to June 2008). Key words relating to the domains of randomized controlled trials and back pain were used, as recommended by the Cochrane Back Review Group.[19] Terms for motor control and specific stabilization exercises were extracted from the review by Ferreira et al.[16] Subject subheadings and word truncations, according to each database, were used. There was no language restriction.

One reviewer (LGM) screened search results for potentially eligible studies, and 2 reviewers (LGM, CGM) independently reviewed articles for eligibility. A third independent reviewer (JL) resolved any disagreement about inclusion of trials. Authors were contacted if more information about the trial was needed to allow inclusion of the study. Researchers who published in the area were contacted to help identify gray literature and articles in press. Citation tracking was performed using ISI Web of Science, and a manual search of the reference lists of previous reviews and the eligible trials was performed.

Study Selection

The reviewers followed a research protocol, developed prior to the beginning of the review, that included

a checklist for inclusion criteria. Articles were eligible for inclusion if they were randomized or quasi-randomized controlled trials comparing motor control exercise with a placebo treatment, no treatment, or another active treatment or when motor control exercise was added as a supplement to other interventions. When motor control exercise was used in addition to other treatments, motor control exercises had to represent at least 40% of the total treatment program. This criterion was judged by reading the description of the treatment with the reviewer making a global yes/no judgment.

Trials were considered to have evaluated motor control exercise if the exercise treatment was described as motor control or specific spinal stabilization or core stability exercise and where the protocol described exercise targeting specific trunk muscles in order to improve control and coordination of the spine and pelvis.

Randomized or quasi-randomized controlled trials were included if they explicitly reported that a criterion for entry was nonspecific LBP (with or without leg pain) of at least 6 weeks' duration (nonacute LBP) or recurrent LBP. Studies evaluating individuals of all age groups of either sex were included. Trials were included if one of the following outcome measures had been reported: pain, disability, quality of life, return to work, or recurrence.

Data Extraction and Quality Assessment

The methodological quality of the trials was assessed using the PEDro scale,[22] with scores extracted from the PEDro database. Assessment of quality of trials in the PEDro database was performed by 2 trained independent raters, and disagreements were resolved by a third rater.[23] One study[24] was extracted from a conference proceeding, and, therefore, the PEDro score was not available in the database. However, 2 PEDro raters evaluated the information available in the abstract and in an initial version of a manuscript, and a PEDro score was given. Methodological quality was not an inclusion criterion.

Three independent reviewers (LGM, CGM, JL) extracted data from each included study using a standardized extraction form. Mean scores, standard deviations, and sample sizes were extracted from the studies. When this information was not provided in the trial, the values were calculated or estimated using methods recommended in the *Cochrane Handbook for Systematic Reviews of Interventions*.[25] When there was insufficient information about outcomes to allow data analysis, the authors of the study were contacted, and all authors replied to our inquiries.[24,26–28]

Outcomes were extracted for pain and disability for short-term follow-up (less than 3 months after randomization), intermediate follow-up (at least 3 months but less than 12 months after randomization), and long-term follow-up (12 months or more after randomization). When there were multiple time points that fell within the same category, the one that was closer to the end of the treatment for the short-term follow-up, closer to 6 months for the intermediate follow-up, and closer to 12 months for the long-term follow-up was used. These references for time points were based on guidelines from the Cochrane Back Review Group. Scores for pain and disability were converted to a 0 to 100 scale.[29]

Data Synthesis and Analysis

The studies were grouped into 4 treatment contrasts: (1) motor control versus minimal intervention (no intervention, general practitioner care, education) or motor control as a supplement, (2) motor control versus spinal manipulative therapy, (3) motor control versus exercise, and (4) motor control versus surgery (lumbar fusion). Results were pooled when trials were considered sufficiently homogenous with respect to participant characteristics, interventions, and outcomes. I^2 was calculated using RevMan 4.2* to analyze statistical heterogeneity. I^2 describes the percentage of the variability in effect estimates that is due to heterogeneity rather than sampling error (chance). A value greater than 50% may be considered substantial heterogeneity.[25] When trials were statistically homogeneous ($I^2<50\%$), pooled effects (weighted mean difference) were calculated using a fixed-effect model. When trials were statistically heterogeneous ($I^2>50\%$) pooled estimates of effect (weighted mean difference) were obtained using a random-effects model.[25] When there was a single trial for the comparison, results were expressed as mean differences and 95% CI.

Results

Study Selection

The initial electronic database search resulted in a total of 1,052 articles. Of these, 42 were selected as potentially eligible based on their title and abstract. Through a Web of Science search of these articles, 3 other potentially eligible articles were identified. A total of 45 potentially eligible articles were considered for inclusion, with only 14 eligible for inclusion in this review (Fig. 1). Reasons for exclusion are shown in Figure 1 for those articles[2,3,15,30–57] that were excluded from this review. Only 1 of the 26 experts contacted sent information to us on a new trial for inclusion.

* Copenhagen, Denmark: The Nordic Cochrane Centre, The Cochrane Collaboration, 2003.

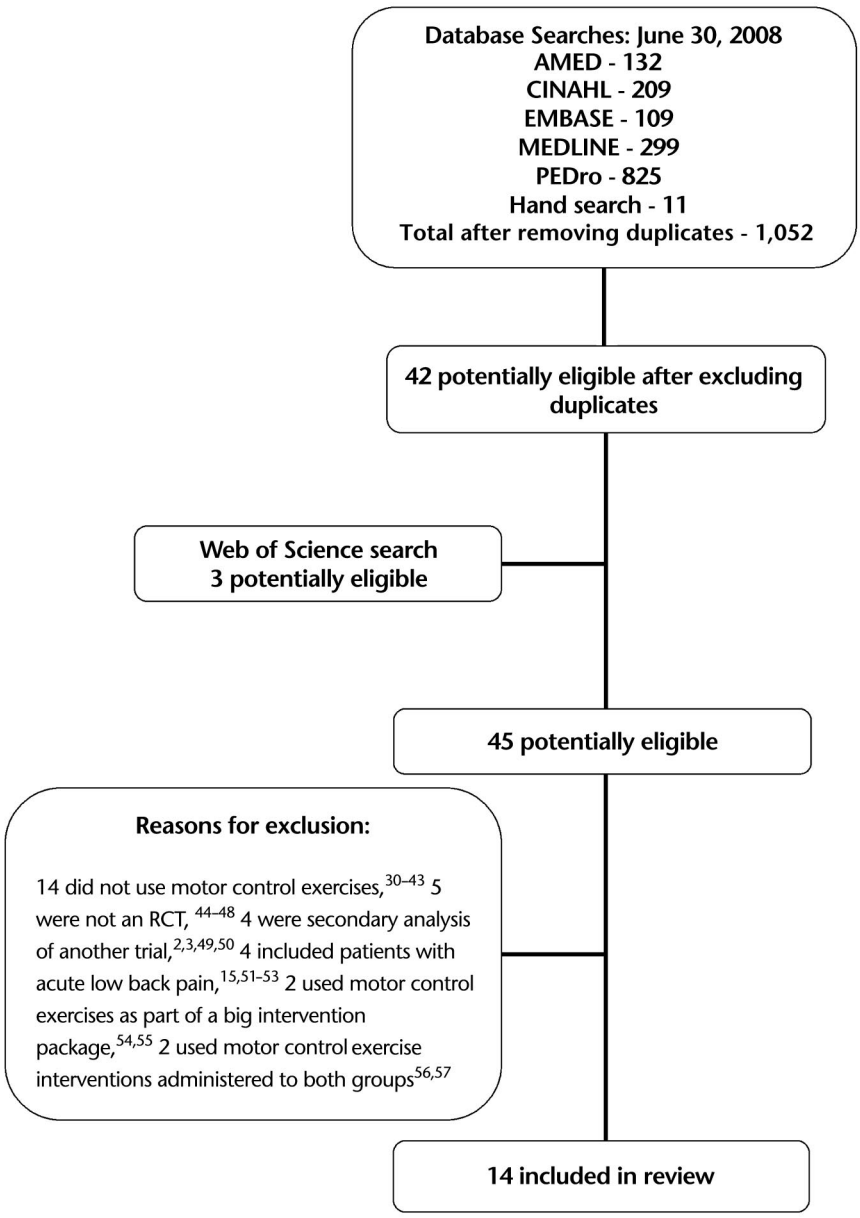

Figure 1.
Flow chart of systematic review inclusion and exclusion. RCT=randomized controlled trial.

A number of randomized controlled trials that were included in previous systematic reviews of motor control exercises were not included in this review. Reasons for exclusion included: patients had acute but not persistent back pain,[15,51,53] patients had neck pain and headache but not back pain,[58] the trial did not use a motor control intervention according to our review definition,[56] and the trial did not have the outcomes of interest.[59,60] Four new trials[13,24,26,61] that were not included in any of the previously published reviews were included in this review, accounting for the addition of 560 patients.

Methodological Quality

The methodological quality assessment using the PEDro scale revealed a mean score of 6 (range=2–8). Blinding of the therapist and blinding of the subject were not used in any of the trials, as would be expected for an exercise therapy study. An intention-to-treat analysis was used in 36% of the trials, and allocation concealment was present in 58% of the trials. One of the articles[24] included in the review was from a conference proceeding, and, there-

fore, not much information on the conduct of the trial was available. With the limited information available, this trial received a score of 2 on the PEDro scale and was the only trial that was a quasi-randomized controlled trial.[24]

Study Characteristics

The 14 randomized controlled trials included in this review compared motor control exercise against another treatment or against no treatment (Tabs. 1 and 2). No placebo-controlled trials were identified. Trials were grouped into 4 treatment contrasts: (1) motor control exercise versus minimal intervention or motor control exercise as a supplement, (2) motor control exercise versus manual therapy, (3) motor control exercise versus other forms of exercise, and (4) motor control exercise versus surgery.

Seven trials (603 patients) were included in the first treatment contrast: 4 trials (343 patients) that compared motor control exercise with minimal intervention (no intervention, general practitioner care, or education)[14,27,62,63] and 3 trials (260 patients) that used motor control exercise as a supplement to other treatment (general exercise or usual physical therapy.[28,64,65] Four trials (523 patients) compared motor control exercise with manual therapy (high- or low-velocity trust).[13,26,64,66] Five trials (508 patients) compared motor control exercise with another form of exercise therapy (pain management, general exercises, or the McKenzie approach).[13,24,26,61,67] One trial (61 patients) compared motor control exercise with lumbar fusion surgery.[68] The characteristics of the motor control exercise programs that were evaluated in each trial are provided in Table 2.

Motor Control Exercise Versus Minimal Intervention or Motor Control Exercise as a Supplement

Of the 7 studies included in this treatment contrast, 4 compared motor control exercise with a minimal intervention program (usual general practitioner care or no intervention)[14,27,62,63] and 3 compared motor control exercise as a supplement to another intervention versus this other intervention alone.[28,64,65] Methodological quality of the articles ranged from 4 to 8. Data for pain, disability, and quality of life were available for pooling at short-term, intermediate, and long-term follow-up. Data were pooled using a random-effects model for all comparisons except for quality of life at intermediate and long-term follow-ups, where a fixed-effects model was used because I^2 was smaller than 50%.

The pooled results favored motor control exercise for pain and disability outcomes at each follow-up, with 4 of the 6 estimates of treatment effect being statistically significant. The random-effects model showed a statistically significant decrease in pain favoring motor control exercise at short-term follow-up (weighted mean difference [on a 0–100 scale]=−14.3 points, 95% CI=−20.4 to −8.1), intermediate follow-up (weighted mean difference=13.6 points, 95% CI=−22.4 to −4.1), and long-term follow-up (weighted mean difference=−14.4 points, 95% CI=−23.1 to −5.7) and in reducing disability at long-term follow-up (weighted mean difference=−10.8 points, 95% CI=−18.7 to −2.8) (Fig. 2). There was no evidence that motor control exercise was effective for improving quality of life.

Motor Control Exercise Versus Manual Therapy

Four trials[13,26,64,66] compared motor control exercise with manual therapy, with pain and disability outcomes measured at short-term, intermediate, and long-term follow-ups and quality of life measured at intermediate and long-term follow-ups. The methodological quality of the articles ranged from 4 to 8. Because I^2 was smaller than 50% for all time points, a fixed-effects model was used to pool the results. The pooled effects for pain and disability outcomes favored motor control exercise, but the effects were always small and reached statistical significance for only 2 of the 6 estimates. There was a significant difference between treatment groups favoring motor control exercise for pain and disability at intermediate follow-up (weighted mean difference=−5.7 points, 95% CI=−10.7 to −0.8 for pain and weighted mean difference=−4.0 points, 95% CI=−7.6 to −0.4 for disability) (Fig. 3). The pooled estimates of treatment effects on quality of life were small, favoring motor control exercise at short-term follow-up and favoring manual therapy at long-term follow-up.

Motor Control Exercise Versus Other Forms of Exercise

Five trials[13,24,26,61,67] compared motor control exercise with another form of exercise therapy. The methodological quality of the trials ranged from 2 to 8. The trial with a methodological quality score of 2 had its PEDro score assessed from a conference proceeding and some information given by the authors.[24] Results were pooled for pain and disability at short-term, intermediate, and long-term follow-ups. Because I^2 was greater than 50% for pain at short-term follow-up and for disability at long-term follow-up, pooled effects for these time points were calculated using a random-effects model. All other pooled effects were calculated using a fixed-effects model. All estimates of treatment effect were small. Five of the 6 estimates favored motor control exercise; however, only one

Table 1.
Details of the Included Randomized Controlled Trials[a]

Article	Patient Characteristics, Sample Size, and Duration of Complaint	Interventions	Outcomes (Measure)	PEDro Score	Article Included in Previous Reviews
Motor control exercises versus minimal intervention or motor control exercises as a supplement					
Niemisto et al,[62] 2003	Patients recruited from advertisement Aged 24–46 y Main exclusion criterion: neurological signs or prior back surgery N=204 Duration of LBP >3 mo	Motor control exercises + muscle energy vs usual general practitioner care (education)	Pain (VAS) Disability (ODI) Quality of life (health-related quality of life)	8	Included in Ferreira et al,[16] 2006; Rackwitz et al,[18] 2006; and Hauggaard et al,[17] 2007
Koumantakis et al,[65] 2005	Patients from an orthopedic clinic in a hospital and general practitioners Main exclusion criterion: prior back surgery or radiological signs of spinal instability N=55 Duration of LBP >6 wk	Motor control exercises + general exercises vs general exercises only	Pain (VAS) Disability (RM-24)	7	Included in Ferreira et al,[16] 2006; and Hauggaard et al,[17] 2007
O'Sullivan et al,[14] 1997	Patients with spondylolysis or spondylolisthesis Aged 16–49 y Main exclusion criterion: neurological signs or inflammatory joint disease N=42 Duration of LBP >3 months	Motor control exercises vs usual general practitioner care	Pain (short-form McGill VAS) Disability (ODI)	7	Included in Ferreira et al,[16] 2006; Rackwitz et al,[18] 2006; and Hauggaard et al,[17] 2007
Stuge et al,[28] 2004	Patients from health care practitioners Pelvic girdle pain lateral to L5–S1 Main exclusion criterion: neurological signs N=81 Duration of LBP >6 wk	Motor control exercises + usual physical therapy vs usual physical therapy only	Pain (VAS pain evening) Disability (ODI)	7	Included in Ferreira et al,[16] 2006
Moseley,[27] 2002	Patients from general practitioners and physical therapy clinics Main exclusion criterion: worsening neurological signs N=57 Duration of LBP >2 mo	Motor control exercises + manual therapy + education vs usual general practitioner care	Pain (back pain NRS 0–10) Disability (RM-18)	6	Included in Ferreira et al,[16] 2006; and Rackwitz et al,[18] 2006
Shaughnessy et al,[63] 2004	Patients from orthopedic clinics Aged 20–60 y Main exclusion criterion: neurological signs or inflammatory joint disease N=41 Duration of LBP >3 mo	Motor control exercises vs no intervention	Pain (SF-36 bodily pain) Disability (RM-24) Quality of life (SF-36 general health)	5	Included in Hauggaard et al,[17] 2007
Goldby et al,[64] 2006[19]	Patients from physical therapy department of a hospital Aged 18–65 y Main exclusion criterion: neurological signs or prior back surgery N=124 Duration of LBP >3 wk	Motor control exercises + education vs education only	Pain (back pain NRS 0–100) Disability (ODI) Quality of life (Nothingham Health Profile)	4	Included in Ferreira et al,[16] 2006; and Hauggaard et al,[17] 2007

(Continued)

Table 1.
Continued

Article	Patient Characteristics, Sample Size, and Duration of Complaint	Interventions	Outcomes (Measure)	PEDro Score	Article Included in Previous Reviews
Motor control exercises versus manual therapy					
Ferreira et al,[13] 2007	Patients seeking care from physical therapy departments of public hospitals Aged 18–80 y Main exclusion criterion: neurological signs or prior back surgery N=160 Duration of LBP >3 mo	Motor control exercises vs spinal manipulative therapy	Pain (VAS) Disability (RM-24)	8	Not included in previous reviews
Critchley et al,[26] 2007	Patients recruited from referrals by specialists or primary care practitioners to physical therapy departments of hospitals Aged 18 y or older With or without leg symptoms or neurologic signs Main exclusion criterion: prior spinal surgery, hematologic disease, or had physical therapy in the last 6 mo N=143 Duration of LBP >12 wk	Motor control exercises vs manual therapy + home exercises vs pain management program	Pain (VAS) Disability (RM-24) Quality of life (EQ-5D)	7	Not included in previous reviews
Rasmussen-Barr et al,[66] 2003	N=47 Duration of LBP >6 wk	Motor control exercises vs spinal manipulative therapy	Pain (VAS) Disability (ODI)	5	Included in Ferreira et al,[16] 2006; and Rackwitz et al,[18] 2006
Goldby et al,[64] 2006	Patients from physical therapy department of a hospital Aged 18–65 y Main exclusion criterion: neurological signs or prior back surgery N=173 Duration of LBP >3 wk	Motor control exercises + education vs spinal manipulative therapy + education	Pain (back pain NRS 0–100) Disability (ODI) Quality of life (Nothingham Health Profile)	4	Included in Ferreira et al,[16] 2006; and Hauggaard et al,[17] 2007
Motor control exercises versus other forms of exercise					
Ferreira et al,[13] 2007	Patients seeking care from physical therapy departments of public hospitals Aged 18–80 y Main exclusion criterion: neurological signs or prior back surgery N=160 Duration of LBP >3 mo	Motor control exercises vs general exercises	Pain (VAS) Disability (RM-24)	8	Not included in previous reviews
Critchley et al,[26] 2007	Patients recruited from referrals by specialists or primary care practitioners to physical therapy departments of hospitals Aged 18 y or older With or without leg symptoms or neurologic signs Main exclusion criterion: prior spinal surgery, hematological disease, or had physical therapy in the last 6 mo N=141 Duration of LBP >12 wk	Motor control exercises vs manual therapy + home exercises vs pain management program	Pain (VAS) Disability (RM-24) Quality of life (EQ-5D)	7	Not included in previous reviews

(Continued)

Table 1.
Continued

Article	Patient Characteristics, Sample Size, and Duration of Complaint	Interventions	Outcomes (Measure)	PEDro Score	Article Included in Previous Reviews
Kladny et al,[67] 2003	Patients sent to the outpatient rehabilitation department due to back pain Aged 18–55 y Patients with or without radiation or with or without disk hernia or protrusion Main exclusion criteria: prior spinal surgery, arthritis of the joints, injuries, or trauma N=99 Subacute and chronic	Motor control exercises + general exercises vs general exercises + manual therapy	Pain (back pain NRS) Disability (ODI)	5	Included in Ferreira et al,[16] 2006; Rackwitz et al,[18] 2006; and Hauggaard et al,[17] 2007
Miller et al,[61] 2005	Patients from an outpatient physical therapy clinic Aged above 18 y Main exclusion criterion: more than one back surgery or systemic inflammatory disease N=30 Duration of LBP >7 wk	Motor control exercises vs McKenzie approach	Pain (VAS) Disability (functional status 0–100)	5	Not included in previous reviews
Stevens et al,[24] 2007	Patients with nonspecific LBP from the physical medicine and orthopedic surgery department of a hospital Aged 18–65 y Main exclusion criteria: specific LBP, radicular symptoms, back surgery, and neurologic or systemic condition N=78 Duration of LBP >3 mo or recurrent	Motor control exercises + manual therapy (10%) vs general exercises of trunk muscle function and coordination	Pain (VAS) Disability (QBPDS) Quality of life (SF-36 general health)	2	Not included in previous reviews
Motor control exercises versus surgery					
Brox et al,[68] 2003	Patients from departments of orthopedic surgery, neurosurgery, physical medicine, and rehabilitation Aged 25–60 y Spine degeneration or spondylosis had to be present Main exclusion criterion: neurological signs or prior back surgery N=61 Duration of LBP >1 y	Motor control exercises + cognitive behavioral therapy vs surgery	Pain (back pain 0–100 scale) Disability (ODI) Quality of life (life satisfaction scale)	8	Included in Ferreira et al,[16] 2006

[a] LBP=low back pain, ODI=Oswestry Disability Index, VAS=visual analog scale, RM-18=18-item Roland-Morris Disability Questionnaire, RM-24=24-item Roland-Morris Disability Questionnaire, NRS=numerical rating scale, SF-36=Medical Outcome Study 36-Item Short-Form Health Survey, QBPDS=Quebec Back Pain Disability Scale, EQ-5D=EuroQol questionnaire.

Table 2.
Details of the Motor Control Exercises

Article	Duration of Motor Control Intervention	Progression Rule	Home Program	Adherence Mean (SD)	Feedback
Brox et al,[68] 2003	5-wk intervention (1 session in the first week, 2 wk of home program, and another 2 wk of treatment) Average duration was about 25 h per week	Not stated	2 wk of home program	Adherence was 3 (7) sessions per patient	Not stated
Critchley et al,[26] 2007	8 sessions of 90 min	Progression was based on the ability of the patients to maintain a stable and minimally painful spine. The exercises aimed to improve muscle motor control to provide dynamic segmental stability for the lumbar spine.	Not stated	Not stated	Not stated
Ferreira et al,[13] 2007	12 sessions in 8 wk	Progression by incorporating more functional positions and training the coordination of all trunk muscles during those functional tasks	Not stated	Adherence was 9.2 (3.4) sessions per patient	Real-time ultrasound
Goldby et al,[64] 2006	1 session of 1½ h per week for 10 wk	Not stated	Not stated	Not stated	Not stated
Kladny et al,[67] 2003	Not stated	Not stated	Not stated	Stated only that patients did 16.4 (4.8) d of motor control + 9.5 (3.4) d of general exercises	Real-time ultrasound
Koumantakis et al,[65] 2005	2 sessions of 30 to 45 min per week for 8 wk	Progression toward the goal of 10 contractions of 10 s duration (1–2 wk). Progression to functional activities when patients were able to: (1) contract muscle in a specific pattern and (2) perform 10 contractions of 10 s holds (3–5 wk). Heavier-load functional tasks were progressively introduced in the last 3 wk of the program.	Home exercises included	Adherence was 12.12 (2.69) sessions per patient, and home exercises had median of 23.5 sessions	Tactile and pressure cues
Miller et al,[61] 2005	6 wk	Treatment was divided into 3 phases. Phase 1 goal was to perform 10 repetitions of 10-s holds in different positions. Phase 2 goal was contraction of the transversus abdominis and multifidus muscles with loading of the limbs in different positions. Phase 3 goal was more complex loading exercises.	Patients were asked to perform approximately 10–15 min of home exercises	Not stated	Verbal, tactile, and pressure gauge
Moseley,[27] 2002	2 sessions per week for 4 wk	Not stated	Standard home exercises	Not stated	Not stated
Niemisto et al,[62] 2003	1 session per week for 4 wk	Progression was performed by instructing the patients to perform exercises in a more-functional manner and further integrate them in daily activities.			Verbal, visual, tactile, and pressure gauge

(Continued)

Table 2.
Continued

Article	Duration of Motor Control Intervention	Progression Rule	Home Program	Adherence Mean (SD)	Feedback
O'Sullivan et al,[14] 1997	1 session per week for 10 wk	Holding time of exercises was increased gradually, as well as the pressure on biofeedback monitor. Goal was 10 contractions of 10-s holds. Further low loads were applied by adding leverage through limbs. When accurate activation of the co-contraction pattern was achieved, exercises were progressed to functional holding of postures and activities known to previously aggravate patients' symptoms.	Patients were asked to do daily exercises of approximately 10–15 min	Patients completed a daily exercises sheet to monitor adherence, but results were not presented	Pressure gauge
Rasmussen-Barr et al,[66] 2003	1 session of 45 min per week for 6 wk	Exercises were progressed by applying low load to the muscle through the limbs in different positions. Patients were instructed in how to use contraction of the muscles during activities of daily living and in situations that set off pain.	Patients were asked to do daily exercises of approximately 10–15 min	Not stated	Tactile and pressure gauge
Shaughnessy et al,[63] 2004	10 sessions in 10 wk This consisted of two 1-h sessions during week 1, two 30-min sessions during week 2, one 30-min session during each of weeks 3–6, and one 30-min session during weeks 8 and 10.	Contractions were first performed with the goal to achieve 10 contractions of 10-s holds. Once patients were able to perform sustained contractions in low-load postures, the regimen was progressed by adding leverage through limb movements.	Patients performed daily maintenance exercises at home	Not stated	Verbal, visual, tactile, and pressure gauge
Stevens et al,[24] 2007	18 individual sessions of 45 min in 12 wk (2 times per week in the first 6 wk and 1 time per week in the next 6 wk)	Exercises were practiced in different environments and contexts to maximize transfers to daily situations. The physical therapist was free to choose the type of exercise and the progression he felt most suitable for individual patient. Based on continuous clinical examination, the treatment process contained a clear line of progression achieved by changing parameters such as postural load, reduction of attention demands, reduction of speed, or additional strategies to augment performance, with the final goal to obtain functional improvement.	Daily home exercises were encouraged; however, adherence was not assessed	Not stated	Not stated
Stuge et al,[28] 2004	Sessions of 30 to 60 min, 3 days per week, for 18 to 20 wk	First, the focus was on the specific contraction of the transversely oriented abdominal muscle. After approximately 4 wk, loading was progressively increased.	Exercises were mainly performed at home. Patients were encouraged to activate the transversus abdominis muscles regularly during daily activities.	Adherence was 11 sessions per patient. 80% of patients did their exercise program 3 times per week, either at the clinic or at home.	Not stated

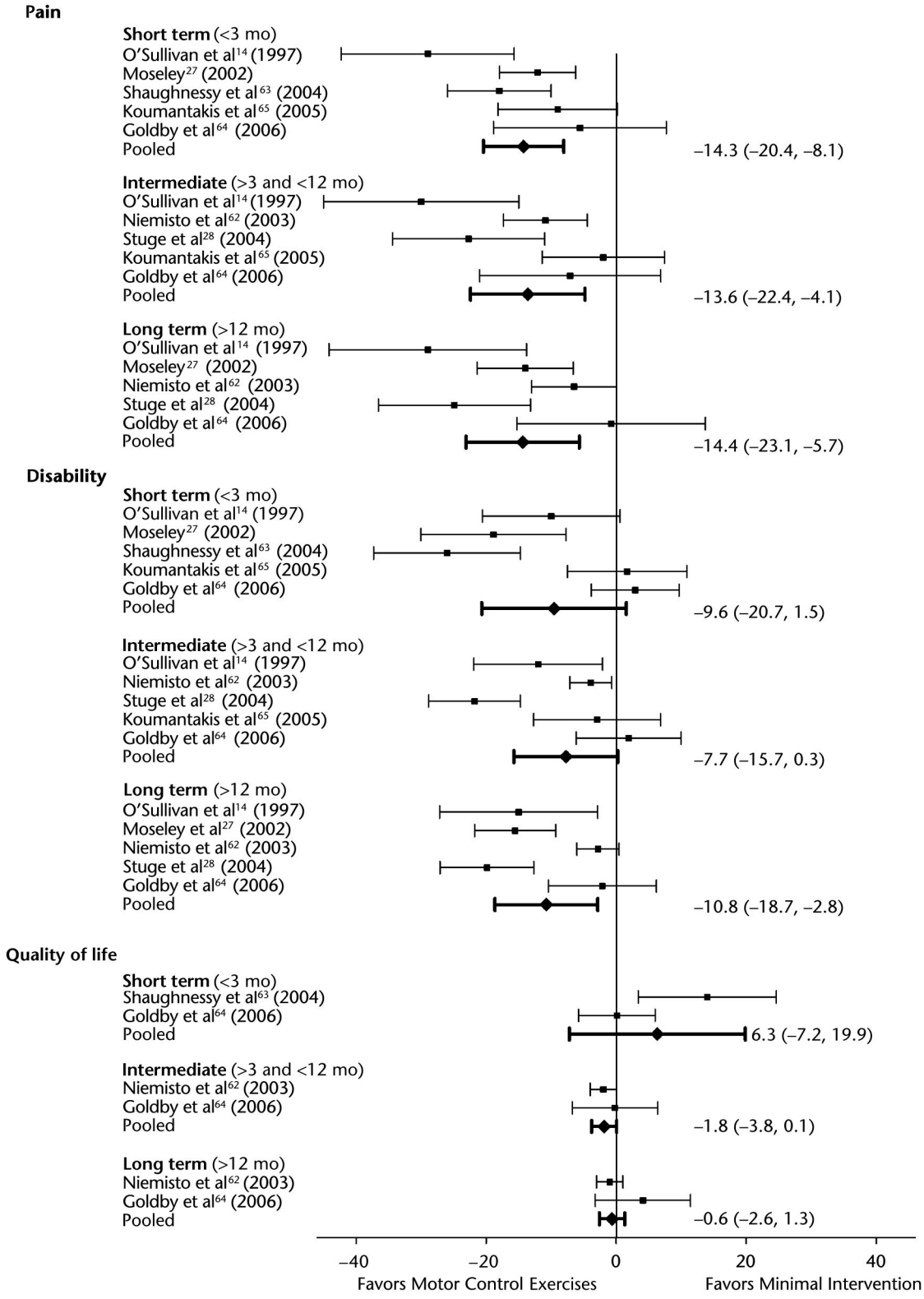

Figure 2.
Forest plot of the results of randomized controlled trials comparing motor control exercises with minimal intervention or motor control exercises as a supplement. Values presented are effect size (weighted mean difference) and 95% confidence interval. The pooled effect sizes were calculated using a random-effects model except for quality of life at intermediate and long-term follow-ups.

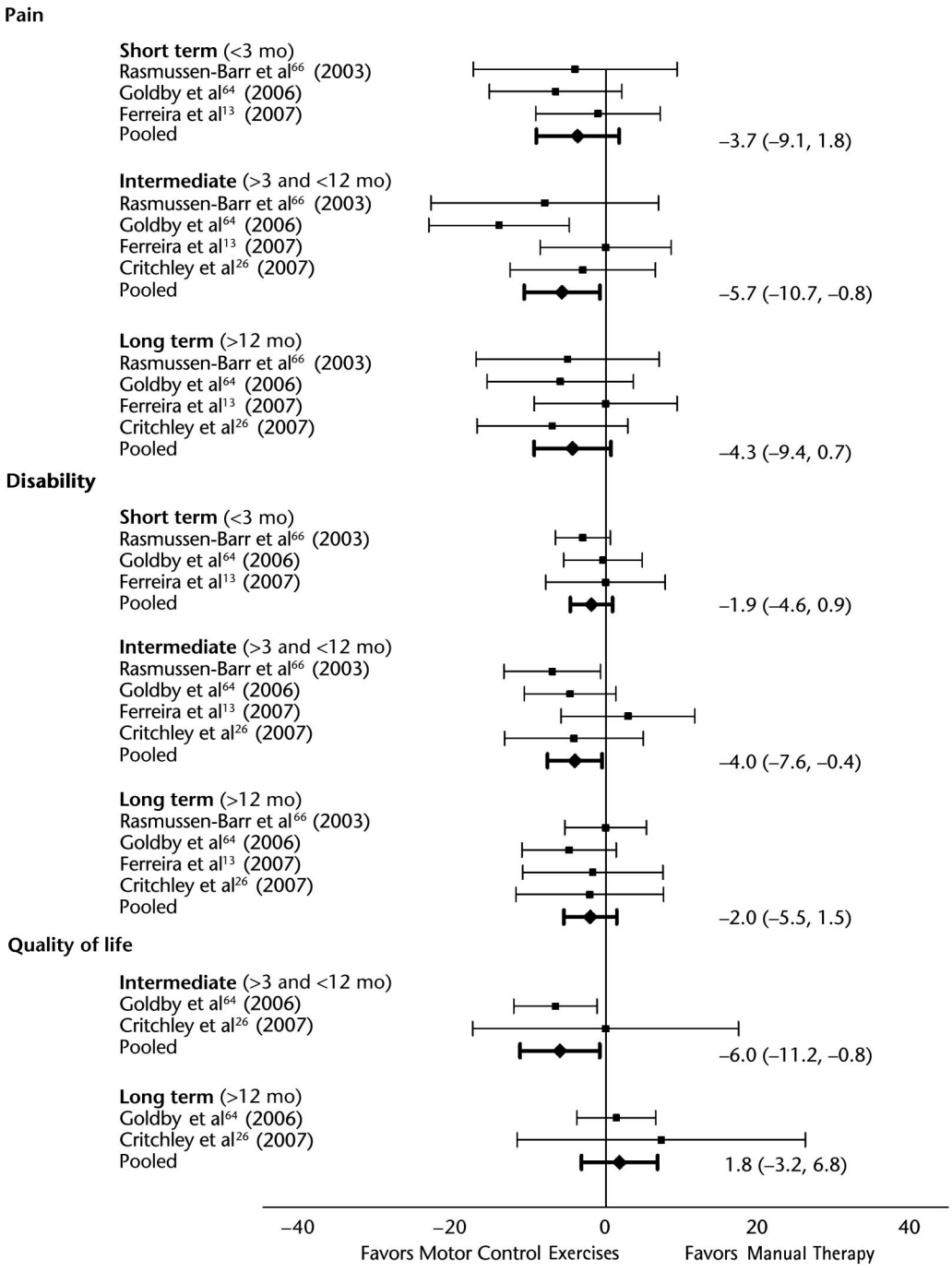

Figure 3.
Forest plot of the results of randomized controlled trials comparing motor control exercises with spinal manipulative therapy. Values represent effect size (weighted mean difference) and 95% confidence interval. The pooled effect size was calculated using a fixed-effect model.

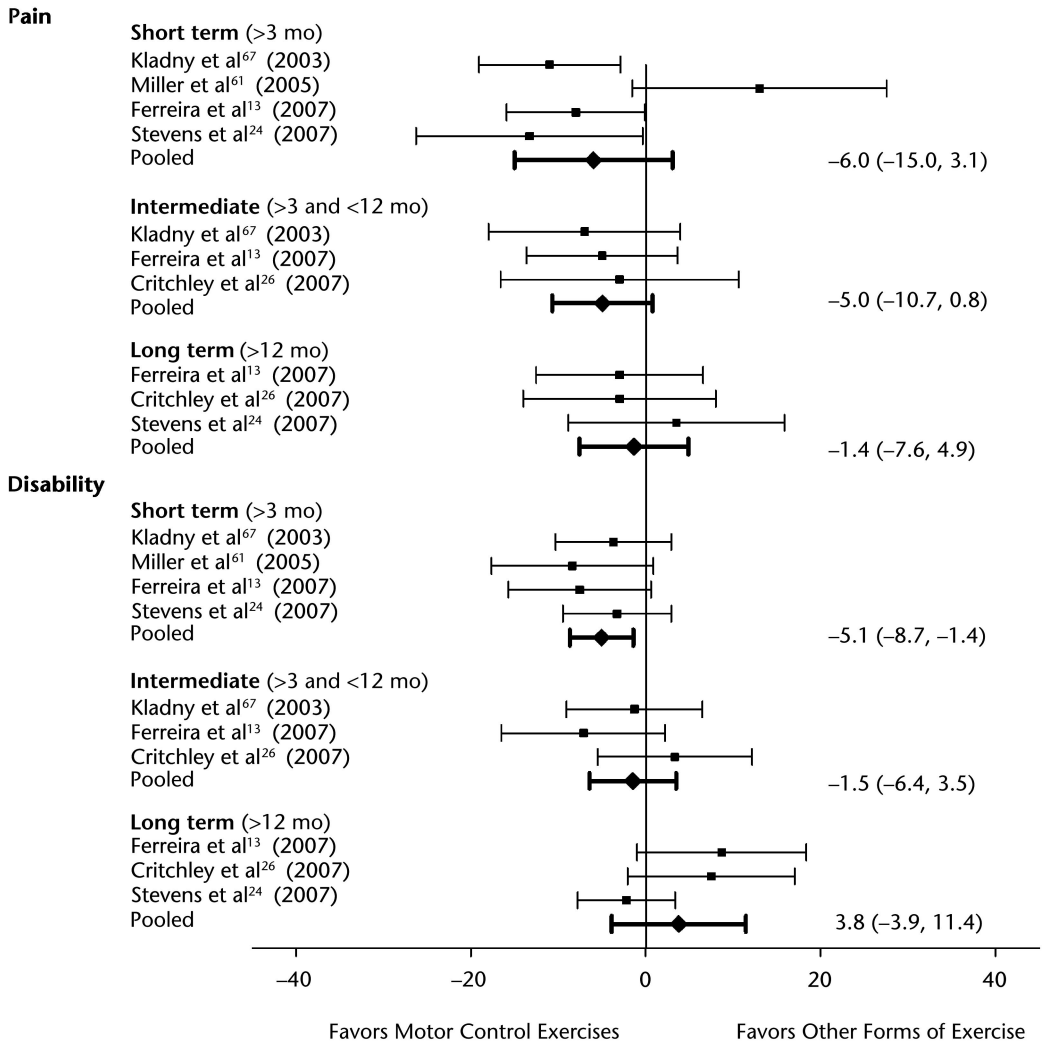

Figure 4.
Forest plot of the results of randomized controlled trials comparing motor control exercises with other forms of exercise. Values represent effect size (weighted mean difference) and 95% confidence interval. The pooled effect size was calculated using a random-effects model for pain at short-term follow-up and for disability at long-term follow-up and using a fixed-effect model for all other comparisons.

effect was statistically significant. The results showed that motor control exercise was better than other forms of exercises only for reducing disability at short-term follow-up (weighted mean difference=−5.1 points, 95% CI=−8.7 to 1.4) (Fig. 4). The results of a single trial[26] showed no difference between treatment groups for quality of life at short-term follow-up.

Motor Control Exercise Versus Surgery

Only one study[68] compared motor control exercise with surgery, with a methodological quality score of 8. Surgery consisted of lumbar fusion with transpedicular screws of the L4–L5 segments or the L5–S1 segments. Brox et al[68] found no statistically significant differences for pain (mean difference [on a 0–100 scale]=−9 points, 95% CI=−22.1 to 3.5), disability (mean difference=−3.3 points, 95% CI=−12.8 to 6.2), and quality of life (mean difference=0.4 points, 95% CI=−1.6 to 0.8) at the long-term follow-up (Fig. 5).

Discussion

This systematic review provides evidence that motor control exercise, alone or as a supplement to another therapy, is effective in reducing pain and disability in patients with persistent, nonspecific LBP. We did not find convincing evidence that motor

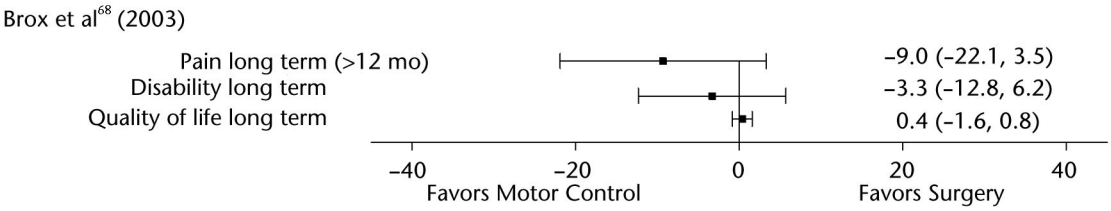

Figure 5.
Forest plot of the results of a randomized controlled trials comparing motor control exercises with surgery. Values represent mean difference and 95% confidence interval.

control exercise was superior to manual therapy, other forms of exercise, or surgery.

Figure 2 shows that there was some variation among studies in the effect sizes for motor control exercise. Features that could influence the treatment effect sizes are characteristics of the patients (eg, symptom duration), characteristics of treatment implementation (eg, program duration, experience of the therapist), and the methodological quality of the trial. Unfortunately, there are too few trials to systematically evaluate the effects of these features using techniques such as meta-regression.

An intriguing finding of this review was that motor control exercise was as effective in reducing pain and increasing quality of life as a less-complex form of exercise therapy that did not incorporate the retraining of specific muscles that often is time consuming to therapists and patients. When taking in consideration the results for disability, motor control exercise was more effective than other forms of exercise only at short-term follow-up, but the point estimate was small (5.1 out of 100), showing differences between interventions that may not be clinically important.

The results of a single trial[68] showed that motor control exercise was not more effective than surgery. This finding is interesting because both interventions target the restoration of spinal stability, and although spinal stability was not directly measured, the findings suggest that the motor control approach is as effective in maintaining stability as an invasive intervention that creates stability by fusing the spine. However, this was the finding of a single trial, and more research is needed to confirm the results.

Although a motor control intervention has been shown to reduce pain, it is still unknown whether these changes are accompanied by improvements in measures of motor control. Tsao and Hodges[69] have shown improvements in motor control (anticipatory contraction of the transversus abdominis muscle during arm movement) after a single treatment session where the isolation of the transversus abdominis muscle was trained. In a different trial, Hall and colleagues[70] did not find that motor control (anticipatory contraction of the transversus abdominis muscle during arm movement and a walking task) changed after training the trunk muscles in a nonisolated manner. Therefore, the results of these 2 studies support the principles of a motor control intervention where the isolated training of the deep trunk muscles is emphasized. However, there has not been a published randomized controlled trial that used clinical and physiological measures to detect improvements in motor control that can be associated with improvements in pain and disability and the maintenance of these changes.

One question that is still to be answered is whether individuals with reduced motor control respond best to this intervention or whether there are other clinical features that can be used to define a subgroup of patients who will respond best to this type of intervention.

A standard protocol and definitions for motor control exercise are yet to be established, and this is reflected in the wide variation among trials in how the exercise was named and implemented (Tab. 2). Although in most cases O'Sullivan et al[14] and Richardson et al[71] were cited as references, it is apparent from inspection of the articles that the interventions in the trials were quite heterogeneous. There was variation in the duration of the exercise program, progression rule, use of home exercise programs, and type of feedback used with the motor control intervention. As an illustration, the program lasted 10 weeks in the trial by O'Sullivan et al, whereas the program lasted 18 to 20 weeks in the trial by Stuge et al.[28] In the trial by Ferreira et al,[13] ultrasound was used for feedback, and Stuge et al[28] used Terapi Master exercise equipment[†]: 2 elements missing from the trial by O'Sullivan and colleagues.

[†] Nordisk Terapi A/S, Kilsund 4290, Staubo, Norway.

Detailed comparison among trials is difficult because in many trials the authors did not thoroughly describe the motor control intervention that was evaluated. Accordingly, although we can conclude from this review that motor control exercise is an effective treatment for persistent LBP, the optimal way to implement this intervention is not yet clear.

When looking at the quality of the trials included in this review, a mean score of 6 can be considered a high score because these trials were exercise trials where it is impossible to blind the treatment provider and subjects, and, therefore, the maximum PEDro score that can be achieved is 8. However, because some trials were of lower methodological quality, they potentially present biased (and overly optimistic) estimates of treatment effects. To assess the impact of the lower-quality studies on the review conclusions, a sensitivity analysis with exclusion of trials with scores lower than 5[24,64] was performed. When the lower-quality studies were deleted, the effect size unexpectedly increased slightly for pain and disability outcomes (we did not conduct a sensitivity analysis for quality of life because the exclusion of these trials would leave only one trial in the treatment contrast). Therefore, we do not believe that our conclusion that motor control exercise is effective (compared with minimal intervention or when used as a supplement) is an artifact of the inclusion of low-quality trials.

This review not only includes 4 new trials that were not included in previous reviews, accounting for the addition of 560 patients, but also allowed the use of a meta-analytical approach with the inclusion of a greater number of articles into each treatment contrast. The pooled results of this systematic review showed smaller and more-precise estimates of treatment effects when compared with the pooled results of Ferreira et al.[13] This difference among studies can be seen when looking, for example, at the motor control exercise versus minimal intervention contrast. For this contrast, Ferreira et al[13] included 2 trials and found an effect of −21 on a 0 to 100 scale (95% CI=−32 to −9) for pain, whereas we found, based on 5 trials, an effect of −14.3 (95% CI=−20.4 to −8.1).

Although it has been only recently that reviews of motor control exercises have been published, this type of intervention is widely accepted and used in the clinical field around the world. Therefore, it is still crucial that further studies in the area be developed, such as a placebo-controlled trial and trials aiming to identify subgroups of patients who will benefit more from a motor control intervention. More fundamental studies in LBP to establish reliable and valid clinical assessment tools to identify deficits in motor control also are needed.

Conclusion

The results of this systematic review suggest that motor control exercise is more effective than minimal intervention and adds benefit to another form of intervention in reducing pain and disability for people with persistent LBP. The optimal implementation of motor control exercise at present is unclear. Future trials evaluating issues such as dosage parameters, feedback approaches, and effects in defined subgroups are a high priority.

Ms Macedo, Dr Maher, and Dr Latimer provided concept/idea/research design and data collection. Ms Macedo and Dr Maher provided writing and data analysis. Ms Macedo, Dr Maher, and Dr McAuley provided project management. Dr Latimer provided clerical support and consultation (including review of manuscript before submission).

Ms Macedo holds a PhD scholarship jointly funded by The University of Sydney and the Australian Government. Dr Maher's research fellowship is funded by Australia's National Health and Medical Research Council.

This article was received April 3, 2008, and was accepted October 10, 2008.

DOI: 10.2522/ptj.20080103

References

1 Hancock MJ, Maher CG, Latimer J, et al. Systematic review of tests to identify the disc, SIJ or facet joint as the source of low back pain. *Eur Spine J.* 2007;16:1539–1550.

2 Niemisto L, Rissanen P, Sarna S, et al. Cost-effectiveness of combined manipulation, stabilizing exercises, and physician consultation compared to physician consultation alone for chronic low back pain: a prospective randomized trial with 2-year follow-up [with consumer summary]. *Spine.* 2005;30:1109–1115.

3 Niemisto L, Sarna S, Lahtinen-Suopanki T, et al. Predictive factors for 1-year outcome of chronic low back pain following manipulation, stabilizing exercises, and physician consultation or physician consultation alone. *J Rehabil Med.* 2004;36:104–109.

4 Panjabi MM. Clinical spinal instability and low back pain. *J Electromyogr Kinesiol.* 2003;13:371–379.

5 Hodges PW, Richardson CA. Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb. *J Spinal Disord.* 1998;11:46–56.

6 Hodges PW, Richardson CA. Relationship between limb movement speed and associated contraction of the trunk muscles. *Ergonomics.* 1997;40:1220–1230.

7 MacDonald D, Moseley GL, Hodges PW. The function of the lumbar multifidus in unilateral low back pain. Presented at: World Congress of Low Back and Pelvic Pain; 2004; Melbourne, Australia.

8 Moseley GL, Hodges PW, Gandevia S. Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine.* 2002;27:E29–E36.

9 Hodges PW, Richardson CA. Inefficient muscular stabilisation of the lumbar spine associated with low back pain: a motor control evaluation of transversus abdominis. *Spine.* 1996;21:2640–2650.

10 Hides JA, Stokes MJ, Saide M, et al. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine.* 1994;19:165–177.

11 Roy SH, DeLuca CJ, Casavant DA. Lumbar muscle fatigue and chronic low back pain. *Spine.* 1989;14:992–1001.

12 Alaranta H, Tallroth K, Soukka A, et al. Fat content of lumbar extensor muscles in low back disability: a radiographic and clinical comparison. *J Spinal Disord.* 1993;6:137–140.

13 Ferreira ML, Ferreira PH, Latimer J, et al. Comparison of general exercise, motor control exercise and spinal manipulative therapy for chronic low back pain: a randomized trial. *Pain.* 2007;131:31–37.

14 O'Sullivan PB, Phyty GD, Twomey LT, et al. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. *Spine.* 1997;22:2959–2967.

15 Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. *Spine.* 1996;21:2763–2769.

16 Ferreira PH, Ferreira ML, Maher CG, et al. Specific stabilisation exercise for spinal and pelvic pain: a systematic review. *Aust J Physiother.* 2006;52:79–88.

17 Hauggaard A, Persson A. Specific spinal stabilisation exercises in patients with low back pain: a systematic review. *Phys Ther Rev.* 2007;12:233–248.

18 Rackwitz B, de Bie R, Limm H, et al. Segmental stabilizing exercises and low back pain. What is the evidence? A systematic review of randomized controlled trials. *Clin Rehabil.* 2006;20:553–567.

19 Bombardier C, van Tulder MW, Pennick V, et al. Cochrane Back Group. *About the Cochrane Collaboration (Cochrane Review Groups [CRGs]).* 2006:4.

20 Airaksinen O, Brox JI, Cedraschi C, et al. Chapter 4: European guidelines for the management of chronic nonspecific low back pain. *Eur Spine J.* 2006;15(Suppl 2):S192–S300.

21 van Tulder MW, Becker A, Bekkering T, et al. Chapter 3: European guidelines for the management of acute nonspecific low back pain in primary care. *Eur Spine J.* 2006;15(Suppl 2):S169–S191.

22 Maher CG, Sherrington C, Herbert RD, et al. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther.* 2003;83:713–721.

23 Sherrington C, Herbert RD, Maher C, et al. PEDro: a database of randomised controlled trials and systematic reviews in physiotherapy. *Man Ther.* 2000;5:223–226.

24 Stevens V, Crombez G, Parlevliet T, et al. The effectiveness of specific exercise therapy versus device exercise therapy in the treatment of chronic low back pain patients. In: Proceedings of the 6th Interdisciplinary World Congress of Low Back and Pelvic Pain; 2007; Barcelona, Spain; 2007: 177.

25 Higgins J, Green S. *Cochrane Handbook for Systematic Reviews of Interventions 4.2.6* [updated September 2006]. In: The Cochrane Library, issue 4, 2006. Chichester, United Kingdom: John Wiley & Sons Ltd; 2006.

26 Critchley DJ, Ratcliffe J, Noonan S, et al. Effectiveness and cost-effectiveness of three types of physiotherapy used to reduce chronic low back pain disability: a pragmatic randomized trial with economic evaluation [with consumer summary]. *Spine.* 2007;32:1474–1481.

27 Moseley L. Combined physiotherapy and education is efficacious for chronic low back pain. *Aust J Physiother.* 2002;48: 297–302.

28 Stuge B, Laerum E, Kirkesola G, et al. The efficacy of a treatment program focusing on specific stabilizing exercises for pelvic girdle pain after pregnancy: a randomized controlled trial. *Spine.* 2004;29:351–359.

29 van Tulder MW, Furlan A, Bombardier C, et al. Updated method guidelines for systematic reviews in Cochrane Collaboration Back Review Group. *Spine.* 2003;28: 1290–1299.

30 Bendix AF, Bendix T, Lund C, et al. Comparison of three intensive programs for chronic low back pain patients: a prospective, randomized, observer-blinded study with one-year follow-up. *Scand J Rehabil Med.* 1997;29:81–89.

31 Bentsen H, Lindgarde F, Manthorpe R. The effect of dynamic strength back exercise and/or a home training program in 57-year-old women with chronic low back pain: results of a prospective randomized study with a 3-year follow-up period. *Spine.* 1997;22:1494–1500.

32 Cambron JA, Gudavalli MR, Hedeker D, et al. One-year follow-up of a randomized clinical trial comparing flexion distraction with an exercise program for chronic low-back pain. *J Altern Complement Med.* 2006;12:659–668.

33 Friedrich M, Gittler G, Halberstadt Y, et al. Combined exercise and motivation program: effect on the compliance and level of disability of patients with chronic low back pain—a randomized controlled trial. *Arch Phys Med Rehabil.* 1998;79: 475–487.

34 Frost H, Lamb SE, Doll HA, et al. Randomised controlled trial of physiotherapy compared with advice for low back pain. *BMJ.* 2004;329:708–713.

35 Gudavalli MR, Cambron JA, McGregor M, et al. A randomized clinical trial and subgroup analysis to compare flexion-distraction with active exercise for chronic low back pain. *Eur Spine J.* 2006;15:1070–82.

36 Helewa A, Goldsmith CH, Lee P, et al. Does strengthening the abdominal muscles prevent low back pain: a randomized controlled trial. *J Rheumatol.* 1999;26: 1808–1815.

37 Koes BW, Bouter LM, van Mameren H, et al. The effectiveness of manual therapy, physiotherapy, and treatment by the general practitioner for nonspecific back and neck complaints: a randomized clinical trial. *Spine.* 1992;17:28–35.

38 Lie H, Frey S, Lie H, et al. Mobilizing or stabilizing exercise in degenerative disk disease in the lumbar region? [in Norwegian]. *Tidsskrift for Den Norske Laegeforening.* 1999;119:2051–2053.

39 Mannion AF, Muntener M, Taimela S, et al. Comparison of three active therapies for chronic low back pain: results of a randomized clinical trial with one-year follow-up. *Rheumatology.* 2001;40:772–778.

40 Nelson BW, O'Reilly E, Miller M, et al. The clinical effects of intensive, specific exercise on chronic low back pain: a controlled study of 895 consecutive patients with 1-year follow up. *Orthopedics.* 1995; 18:971–981.

41 Shaughnessy A. Can a specific exercise program combined with brief counseling by a physical therapist offer benefits over usual care? *Evidence-Based Practice.* 1999;2:1–2.

42 Suni J, Rinne M, Natri A, et al. Control of the lumbar neutral zone decreases low back pain and improves self-evaluated work ability: a 12-month randomized controlled study. *Spine.* 2006;31:E611–E620.

43 Timm KE. A randomized-control study of active and passive treatments for chronic low back pain following L5 laminectomy. *J Orthop Sports Phys Ther.* 1994;20:276–286.

44 Freburger JK, Carey TS, Holmes GM, et al. Effectiveness of physical therapy for the management of chronic spine disorders: a propensity score approach. *Phys Ther.* 2006;86:381–394.

45 Hicks GE, Fritz JM, Delitto A, et al. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. *Arch Phys Med Rehabil.* 2005;86:1753–1762.

46 Kasai R. Current trends in exercise management for chronic low back pain: comparison between strengthening exercise and spinal segmental stabilization exercise. *J Phys Med Sci.* 2006;18:97–105.

47 Ljungkvist I, Ljungkvist I. Short- and long-term effects of a 12-week intensive functional restoration programme in individuals work-disabled by chronic spinal pain. *Scand J Rehabil Med Suppl.* 2000;40:1–14.

48 Weinhardt C, Heller KD, Weh L, et al. Non-operative treatment of chronic low back pain: specific back muscular strength training versus improvement of physical fitness. *Zeitschrift fur Orthopadie und Ihre Grenzgebiete.* 2001;139:490–495.

49 Koumantakis GA, Watson PJ, Oldham JA, et al. Supplementation of general endurance exercise with stabilisation training versus general exercise only: physiological and functional outcomes of a randomised controlled trial of patients with recurrent low back pain. *Clin Biomech.* 2005;20: 474–482.

50 Stuge B, Veierod MB, Laerum E, et al. The efficacy of a treatment program focusing on specific stabilizing exercises for pelvic girdle pain after pregnancy: a two-year follow-up of a randomized clinical trial. *Spine.* 2004;29:E197–E203.

51 Cairns MC, Foster NE, Wright C, et al. Randomized controlled trial of specific spinal stabilization exercises and conventional physiotherapy for recurrent low back pain. *Spine.* 2006;31:E670–E681.

52 Gagnon LH. *Efficacy of Pilates Exercises as Therapeutic Intervention in Treating Patients With Low Back Pain* [dissertation]. Knoxville, TN: University of Tennessee; 2005:119.

53 Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. *Spine.* 2001;26:E243–E248.

54 Aure OF, Nilse JH, Vasseljen O. Manual therapy and exercise therapy in patients with chronic low back pain. *Spine.* 2003;28:525–532.

55 Monticone M, Barbarino A, Testi C, et al. Symptomatic efficacy of stabilizing treatment versus laser therapy for sub-acute low back pain with positive tests for sacroiliac dysfunction: a randomized clinical controlled trial with 1-year follow-up. *Europa Medicophysica*. 2004;40:263–268.

56 Lewis JS, Hewitt JS, Billington L, et al. A randomized clinical trial comparing two physiotherapy interventions for chronic low back pain. *Spine.* 2005;30:711–721.

57 Riipinen M, Niemisto L, Lindgren KA, et al. Psychosocial differences as predictors for recovery from chronic low back pain following manipulation, stabilizing exercises and physician consultation or physician consultation alone. *J Rehabil Med.* 2005; 37:152–158.

58 Jull GA, Trott P, Potter H, et al. A randomized controlled trial of exercises and manipulative therapy for cervicogenic headache. *Spine.* 2002;27:1835–1843; discussion 1843.

59 Danneels LA, Cools AM, Vanderstraeten GG, et al. The effects of three different training modalities on the cross-sectional area of the paravertebral muscles. *Scand J Med Sci Sports.* 2001;11:335–341.

60 Danneels LA, Vanderstraeten GG, Cambier DC, et al. Effects of three different training modalities on the cross-sectional area of the lumbar multifidus muscle in patients with chronic low back pain. *Br J Sports Med.* 2001;35:186–191; comment in 2001; 35:186–191.

61 Miller ER, Schenk RJ, Karnes JL, et al. A comparison of the McKenzie approach to a specific spine stabilization program for chronic low back pain. *Journal of Manual and Manipulative Therapy.* 2005;13: 103–112.

62 Niemisto L, Lahtinen-Suopanki T, Rissanen P, et al. A randomized trial of combined manipulation, stabilizing exercises, and physician consultation compared to physician consultation alone for chronic low back pain. *Spine.* 2003;28:2185–2191.

63 Shaughnessy M, Caulfield B, Shaughnessy M, et al. A pilot study to investigate the effect of lumbar stabilisation exercise training on functional ability and quality of life in patients with chronic low back pain. *Int J Rehabil Res.* 2004;27:297–301.

64 Goldby LJ, Moore AP, Doust J, et al. A randomized controlled trial investigating the efficiency of musculoskeletal physiotherapy on chronic low back disorder. *Spine.* 2006;31:1083–1093.

65 Koumantakis GA, Watson PJ, Oldham JA. Trunk muscle stabilization training plus general exercise versus general exercise only: randomized controlled trial of patients with recurrent low back pain. *Phys Ther.* 2005;85:209–225.

66 Rasmussen-Barr E, Nilsson-Wikmar L, Arvidsson I, et al. Stabilizing training compared with manual treatment in sub-acute and chronic low-back pain. *Man Ther.* 2003;8:233–241.

67 Kladny B, Fischer FC, Haase I, et al. Evaluation of specific stabilizing exercise in the treatment of low back pain and lumbar disk disease in outpatient rehabilitation. *Zeitschrift fur Orthopadie und Ihre Grenzgebiete.* 2003;141:401–405.

68 Brox JI, Sørensen R, Friis A, et al. Randomized clinical trial of lumbar instrumented fusion and cognitive intervention and exercise in patients with chronic low back pain and disc degeneration. *Spine.* 2003; 28:1913–1921; comment in 2004;29: 1913–1921.

69 Tsao H, Hodges PW. Immediate changes in feedforward postural adjustment following voluntary motor training. *Exp Brain Res.* 2007;181:537–546.

70 Hall L, Tsao T, MacDonald D, et al. Immediate effects of co-contraction training on motor control of the trunk muscles in people with recurrent low back pain. *J Electromyogr Kinesiol.* 2007 Nov 21 [Epub ahead of print].

71 Richardson CA, Jull GA, Hodges PW. *Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain*. Edinburgh, Scotland: Churchill Livingstone; 1999.